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FATIGUE LOADING ON Ti -6Al-4V CRUCIFORM SHAPE WELDED JOINTS WITH DIFFERENT WELD BEAD SHAPES

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ABSTRACT

Estimation of fatigue life was carried out on TIG welded joints of TI6AL4V cruciform shape using S-N curve applying fracture mechanics approach for predicting propagation of cracks. Fatigue tests are carried out with stress ratio R =0.1, considering the constant amplitude and frequency 10HZ using 100 KN servo hydraulic universal testing machine. Fatigue tests, tensile tests and hardness tests revealed that a convex shape, weld joint is having better performance when compared to others Joints. The studies are based on the theoretical fatigue life and experimental fatigue life values are compared for the validation of results and both studies are correlated with AWS D1.9 2007. The behaviour of welds under fatigue crack growth of are related to mechanical properties of the different weld bead shapes, joints, and the convex shape, weld with less stress exhibited higher fatigue resistance and records maximum fatigue life The main objective of this study is the theoretical and experimental analysis of the change in fatigue life, crack growth, SIF and SEM analysis of with different weld bead shapes and constant welded plate thickness with different L/Tp ratio.

KEYWORDS: *Convex Shape, Weld Bead Shapes & Welded Plate Thickness*

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Original Article

INTRODUCTION

Ti-6Al-4V (Grade5) has a predominant characteristic such as excellent corrosion resistance, good weight to strength ratio, toughness, having a low thermal expansion rate, the cruciform welded joints made with TI6Al4V are used in civil industries, military vehicles, bridge girders, nuclear engineering, space vehicles, are occurring to different loads leads to occurrence of small cracks to grow and slowly the cracks propagate and finally component will fail. A thorough study of the measurement of crack growth is necessary to prevent the failure of the component with prior prediction, detection of the crack before failure of the component.

This main purpose of a crack growth measurement of the Ti-6Al4V weld joints is to prevent the catastrophic failure for the components which are subjected to variable loads

For a load-carrying cruciform welded joint subjected to high cycle fatigue the parameters that determine the type of failure that is root failure or toe failure are weld geometry and size of unfused portion called as LOP(Lack of penetration) defect [1]. In this paper, a load-carrying cruciform welded joint with a LOP defect is considered and it is subjected to high cycle fatigue.

Fatigue cracks which are initiating from the region of weld at root are very difficult to identify and therefore, such type of weld root cracks will lead to decrease in failure of a joint with less number of cycles when they are compared with the toe cracks of welded joints. Kainuma [2-3] carried out different fatigue tests to estimate the number of cycles recorded by the fillet welded cruciform joints and observed that major failures are occurred at the weld root regions. Fatigue cracks will begin at the region fillet weld toe if the fillet weld size is great enough and begin at weld root and when the size of weld size is insufficient [4] The Titanium used in the present studies is used in Aerospace and ship industry. Chemical studies and Mechanical tests were carried out on specimens of the TI6AL4V as per standards of ASTM E 8 M—11 [5]. The root failures are able to avoid when the weld proportions are made suitable to the thickness of plate; crack growth of joints depends up on the material, type of loading and the configurations of the weld and plate. Kainuma and Mori [6] carried out the tests to examine the life of welded joints with failure at weld root.

Branco CM., Smith IFC & Stig Berge [7–9], identified that many investigations on estimating the life of specimens through experiment methods based on toe failure for fillet welded joints. Very few studies [10-11] observed that fatigue behavior of joints initiating from root region. Therefore, in this study various weld shape joints are fabricated with titanium material and tested to predict life and propagation of crack. A lot of investigations have been done on welded joints and observed behavior of fatigue strength, fatigue crack is from the weld root [12]

Most of the studies observed that the results focuses on the surface characteristics, effect of stress ratio, crack at root and toe, SIF and behavior of crack growth [13]. But, till now no research work is carried out to compare the crack growth behaviour of TIG welded joints of Ti-6Al-4V alloy (ASTM B265) with three different weld bead shapes and therefore, the present work was carried out to identify properties of welded joints. Number of cycles, crack length, SIF, fatigue crack growth behaviour and SEM analysis of fractured specimens of concave, convex and flat weld bead shapes for different stress ranges. Scanning electron microscope (with EDS) has been used for micro structural studies. It is observed that the specimens having pre crack along the weld centre line leads to a less propagation rate of crack and greater threshold stress intensity when compare to the parent metal of specimen [14]

EXPERIMENTAL PROCEDURE

The samples of welded joints are fabricated with the help of main plate or flange plate and two cross plates. Main plate dimension were 100mm x24mmx 6mm and each cross plate 100mm x 24mm x 6mm. the fillet welds are made between the flange plate and cross plate by depositing the weld metal. TIG welding is used to form cruciform shape joints with help of ER Ti5 filler material (As per AWS) with the help of the TIG welding machine. TIG welding process is chosen to manufacture the joint and multi pass welding procedures are employed. The main reason for consideration of TIG Welding is the thickness of the plate is more than 5mm.It is not possible to do EBW, LBW for fatigue analysis. The Titanium used in the present studies is used in Aerospace and ship industry. Tension tests are carried out on specimens of the TI6AL4V.Mechanical properties of the specimens are examined by conducting various tests on tensile and fatigue machines as per standards of ASTM E 8 M-11 [5].

Ultra-sonic testing was done to all specimens for knowing the defects in welded joints, few specimens were rejected as we identified the cracks in welded regions and specimens which are not having any defects are undergone tensile testing and fatigue testing. The test was done at two positions

- Horizontal movement of the probe near to weld toe region.
- Placing the probe on Top of vertical plate and the ultrasonic signals towards the weld through metal. Based on the physical observation the defects are identified.

Figure 1: Ultra Sonic Testing of Fabricated Specimens

Table 1: Compositions of TI6AL4V with Weight Percent

Ti 6al 4v Grade 5 Chemical Composition in Weight Percent							
TiGr5 Wt(%)	C	Al	V	Fe	H	N	0
	0.08	5.8	4.0	0.3	0.015	0.03	0.23

TENSILE TEST OF WELDED SPECIMENS

Before conducting Fatigue test, it is necessary to identify the yield point of welded specimen based on this point fatigue load or applied stress should be given to a fatigue testing machine.

Tensile testing is a primary test in where a specimen is subjected to a controlled tension test until failure. Tensile test is conducted in three different weld bead shape fillet joints; Tensile strength and yield strength values are more in Convex shape specimen. Experiment investigation observed that, when toe radius increases, tensile strength is increases.

The specimen was failed at the ultimate point of 890 Mpa (i.e. 133 KN and area of cross section 144mm^2) and the yield point is 820MPa. Stress is applied on the specimen with a range of 80%, 60%, 50% and 30% of yield point. When the load is applied from 0kN to maximum value, yielding of the specimen will start at 115kN and corresponding deflection is 18 mm. tensile test was carried out till the specimens fail until maximum load (133KN) is attained. Ultimate tensile strength attained is 895N/mm^2, Yield stress is 785.N/mm^2. The UTS for the concave shape specimen is around 830N/mm^2, for a flat shape specimen is around 895N/mm^2, and convex shape specimen is around 1006 N/mm^2

Table 2: Experimental Layout Using L_9 Orthogonal Array

Control Factors	Dof	Seq SS	AdjMS	F	% of Contribution
current A	2	816	408	8.4	25.28
voltage B	2	1680	840	34.6	52.06
speed	2	634	317	13.0	19.64
Error	2	97	48.5		3.02
Total	8	3227			100%

In the tensile test procedure, specimens consistently failed in the welded region, but few are failed near to the upper gripper area. This phenomenon represents that the weld region is relatively weaker when compared to other regions and therefore the strength of the joint is regulated by the weld metal deposition and the strength of the joint. [15] but in present work welded specimen is broken out at the outside of weld region. By optimizing the welding parameters using

Taguchi method the output parameters (UTS) is determined.Experiments were performed based on L9 orthogonal array based Taguchi method and the number of experiments conducted and responses were recorded show in Table 2.

The percentage contribution of welding voltage is 52.06%, Welding current is 25.28% and voltage 19.64% and the Error is 3.02 %. It can be found that the voltage is the most significant welding parameters for affecting the tensile strength.

FATIGUE TESTING OF SPECIMENS

The tests were done by using a ±150 KN capacity fatigue rated UTM. Number of cycles are measured from the based on standard fatigue test procedure as per A S T M E466-96 Cruciform shape welded Joints are placed in the grippers and experiments were conducted with constant ratio (R=0.1) and exciting load is applied on the cross plate of specimen with frequency of 10Hz.as shown in Figure 3. The tests done at different values of stress based on the yield point stress of the material. The specimens should test based on the percentages at 60, 70 & 85 % of yield point strength of the material. The range of stress values is 152 MPa, 280 MPa, 397MPa, 540 MPa and 670 MPa. Three numbers of cycles which cause the fatigue failure of the specimen was consider as life (N_f) and failure up to 1 million cycles are able to predictable for (S-N) curve [16] fatigue assessment methods to the increase of fatigue life, are represented in the IIW guidelines [17]. Crack initiation takes place at upper weld toe and propagation is along the weld region and it is observed that for flat weld shape the number of cycles for crack initiation is more when compare to concave welded specimens. For L/Tp ratio specimen is having less number of cycles or fatigue life when compared with the L/Tp ratio = 1 for all stresses. Crack initiation is at weld toe and crack propagation is along weld region making parabolic profile shape and convex shape will resist the joint from failure. The fatigue life is more when compared to other weld bead shape subjected to maximum stress.

Initiation of crack is at weld root and through the root; the crack propagation is along the width of the plate. Concave specimens are failed at low fatigue life when compare to convex and flat shape specimen for the same stress values was observed that the crack initiating at the root of weld region, if stress is high at the weld toe region, if the range of stress is less. It is identified that decrease in thickness of intermediate plate will leads to decrease the life welded joints.

Figure 2: Specimens for Fatigue Testing

Table 3: Experiment Fatigue Life Values for Different Weld Shapes for Various L/Tp Ratio

Stress Range Vs Number of Cycles	Experiment Results					
	Concave Shape Welded		Convex Shape Welded		Flat Shape Weld	
L/Tp ratio	0.6	1	0.6	1	0.6	1
750MPa (0.95 f_y)	110	430	350	1120	210	745
671MPa (0.83 f_y)	650	1170	1350	2800	1100	1950
541 MPa (0.67 f_y)	2800	4650	5400	7550	3770	6250
397 MPa (0.50 f_y)	9500	19700	11250	69300	9750	28600

Table 3: Contd.,

281 MPa (0.35 f_y)	35700	77400	59500	205000	57540	69570
152MPa (0.2 f_y)	67500	98500	115500	235200	81500	112350
75 MPa (0.1 f_y)	98250	145300	185600	325000	135500	235500

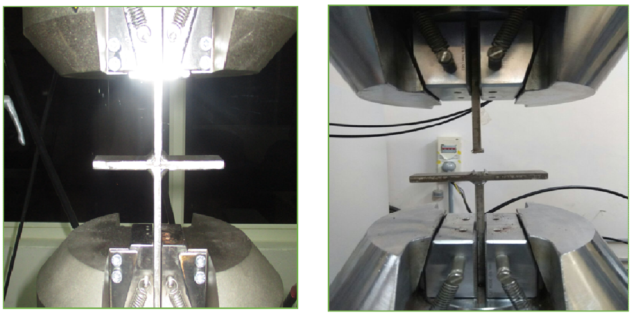

Figure 3: Specimens Placed in Fatigue Testing Machine

RESULTS & DISCUSSIONS

S-N approach and the crack propagated rate approach are of two different methods for determining the life of Specimen. In crack growth rate testing on the material and geometrical parameters were obtained by analysing fatigue crack growth, number of cycles. Comparison of concave, convex and flat shaped welded joint with L/Tp ratio of 0.6 and 1 is as follows.

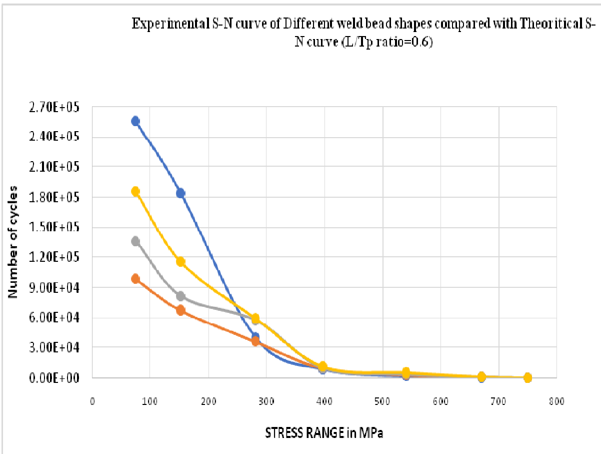

Figure 4(a): Comparison of Experimental and Theoretical S-N values for L/Tp Ratio = 0.6

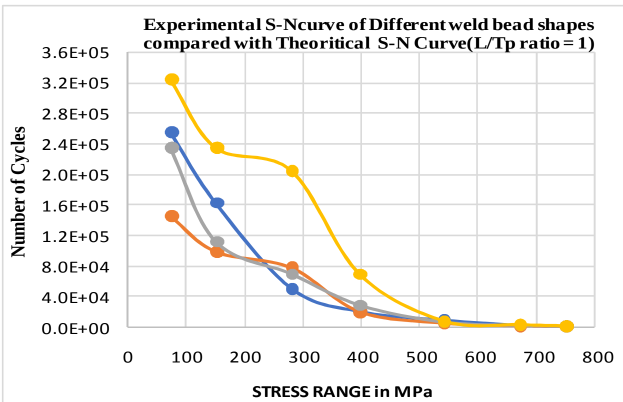

Figure 4(b): Comparison of Experimental and Theoretical S-N Values for L/Tp Ratio =1

From Figure 4a When the comparison is made between theoretical and experimental for L/Tp ratio =0.6 it is observed that at stress at 300 Mpa all welded specimens are failed at around 3×10^4 cycles, which indicates the welded portion is not strong enough compared to the thickness of plate thickness. L/Tp =0.6 are having less fatigue life cycles when compared with L/Tp =1 for improving fatigue life L/Tp ratio is preferred for all types of welded joints for L/Tp =1 specimens convex weld specimens are having more fatigue number of cycles for applied stresses. Theoretical values are less when compared to the experimental values of the convex specimen as shown in Figure 4b. The theoretical fatigue life was compared with values obtained from experiment procedure and there is good accordance between both results is achieved

EFFECT OF L/TP RATIO, SIF AND CRACK LENGTH ON FATIGUE LIFE

The geometrical parameters shows the major impact on fatigue loads and the results of *L*/*T*p ratio on fatigue life for different values of Lack of Penetration size and fillet angle shows that it is evident that the higher the *L*/*T*p ratio will result greater the fatigue strength. The explanation can be simply understood from the expression of stress intensity factor (SIF) range. A polynomial expression which is used for the SIF range (ΔK) by Frank and Fisher [10] and is given as:

$$\Delta K = \frac{\Delta\sigma}{1+2\left(\frac{L}{Tp}\right)} [A_1 + A_2\, a^*][\pi a.\sec(\pi a^*/2)]^{1/2}$$

Theoretically more number of specimens are tested under fatigue crack growth at five different stress levels (Δσ) i.e., 152,281, 397, 541 and 670 MPa. But for evaluation purposes, only two weld sizes i.e., *L*/*T*p . 0.6 & 1.0, were considered. The rate of crack growth is calculated by identifying the slope at the stable growth of various interval length of crack against the related number of cycles for propagation. Based on ASTM E-647 [15] guidelines theoretical calculations were followed.

The minute variation in the growth of the crack and specimen's life is related to difference in number of multi weld passes for different weld bead shapes. Welded specimens with L/Tp ratio 0.6 were made-up by single pass technique but the other welds, of sizes (L/Tp) 0.8 and 1.0, were made-up by using multipass technique [16].

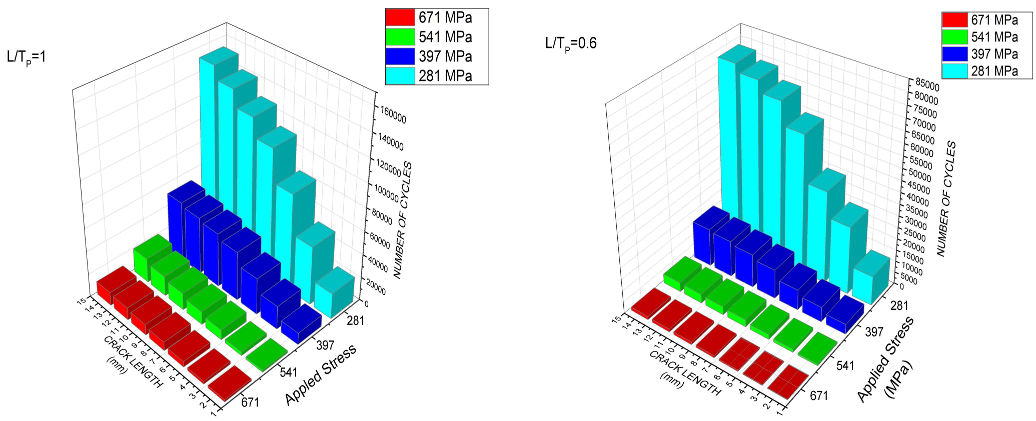

Figure 5: The Relation between Crack Length, Applied Stress and Fatigue Life of Cycles for L/Tp=0.6 & 1

The values of SIF and crack growth rate are represented in Figures 6 & Figure 7. The data points which are represented in the graph mostly related Paris sigmoidal relationship second stage (10^{-3} to 10^{-6} mm/cycle)[18] The 'm' is the

slope used of the line on log plot and 'C' is known of intercept of the line, both are determined from the graph. When L/Tp ratio is 1 the crack growth rate curve ranges between 10^{-6} to 10^{-3} and L/Tp ratio is 0.6 the crack growth rate curve is approximately 10^{-6} to 10^{-2} There is a gradual increase in SIF value when L/Tp =0.6 with in the range more amount of SIF is occurred in this welded specimens.

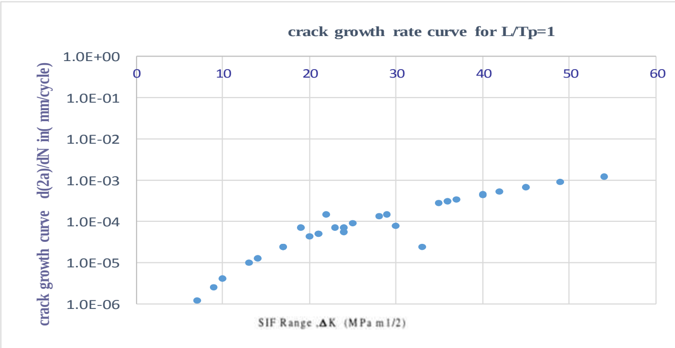

Figure 6: Crack Growth Rate vs SIF Range (L/Tp=1)

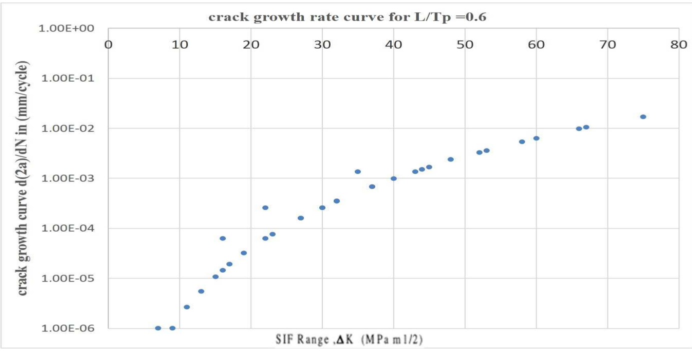

Figure 7: Crack Growth Rate vs SIF Range (L/Tp=0.6)

CONCLUSIONS

The main objective of the present work is to estimate the fatigue strength of different weld bead shapes concave, convex and flat shape on cruciform shape welded joints. Based on the principles of LEFM and Number of cycles of the joints is examined for different stress range values, and experiment values which are obtained were compared with the S–N data predictable based on the recommendations given AWS D1.9.2007. Variation in the shape of weld bead shape reduces the fatigue strength of cruciform weld joints with the load carrying weld joints by considering all the stress ranges. The *L*/*T*p ratio (weld size) has a major effect on the crack propagation life of the welded joints and crack initiation life.

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